Comparative Analysis of Bus Lane Operations in Urban Roads Using Microscopic Traffic Simulation

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Abstract: The research focuses on comparative analysis of three popular types of bus lane operation including roadside exclusive bus lane, bus priority lane and ordinary lane. The analysis is firstly conducted based on simulation tests in PARAMICS with assumed data about traffic situations as well as input parameters. In order to evaluate the results more practically, the research introduced a case study. This case study is conducted at an urban street where there are large numbers of buses and high traffic volumes in Nagaoka City. The results show that with the current traffic situation, the bus priority lane type can help reduce the passenger travel time by 1.2 sec on the 500-meter long segment when compared with the current ordinary lane type. In terms of travel time saving, the paper finally figures out suitable areas for bus lane type applications under various conditions of the main road traffic volume and the number of passengers on the bus.

Key Words: Simulation, Bus priority lane, PARAMICS

1. INTRODUCTION

Deploying public transport system in general as well as bus system in particular is an indispensable trend to relieve traffic congestion and improve traffic quality. However, improving the performance of public transport will usually cause unfavorable conditions for non-bus operations. Therefore, city planners have to decide proper policies to take shape of a harmonious and sustainable traffic system. According to HCM 2000, there are three types of bus lanes. Type 1 bus lanes have no use of the adjacent lane; Type 2 bus lanes have partial use of the adjacent lane, which is shared with other traffic; and Type 3 bus lanes provide for exclusive use of two lanes by buses. It can be seen that, this classification was based on the degree of exclusivity of bus lane. The greater the degree of exclusivity of bus lane and the greater the number of lanes available for buses to maneuver, the greater the bus lane capacity. In Japan, besides the ordinary bus lane type and exclusive bus lane type, another type of bus lane – bus priority lane – has already been deployed (Figure 1) for years. However, there have been very few studies on it. The special thing of this lane type is the complexity of non-buses in choosing lanes and changing lanes to avoid the arriving bus. This priority lane type concerns the degree of exclusivity of not only the bus, but also of the other vehicles. This type can improve the bus travel time significantly and minimize negative impacts on other vehicle types as well.
From the three popular bus lane types in Japan, the scope of this paper only focuses on three cases of traffic operation corresponding to the three mentioned types of bus lane. For a main street with 2 lanes for each direction, the definitions are expressed as follows:

- Roadside exclusive bus lane case: The outer lane is an exclusive bus lane. The inner lane is used mainly for other vehicle types (cars, big trucks, small trucks) and partly for buses which may want to overtake or turn right.
- Bus priority lane case: buses, cars, small trucks and big trucks can use both lanes. However, because the outer lane is the priority lane, non-bus vehicles give up their lanes to buses which are reaching into the recognized distance $D$ of these non-bus vehicles on the priority lane. It means non-buses are allowed to use all lanes, provided that they do not obstruct the bus traveling on the priority lane.
- Ordinary lane case: Buses and non-buses (cars, small trucks and big trucks) can use two lanes and freely change lanes if necessary.

From the above definitions, it can be imagined that the travel time of buses is improved a lot when exclusive bus lanes are deployed as compared to ordinary lane with mixed traffic. However, it is really a waste of road space when the number of buses is usually much less than that of passenger cars in the case of exclusive lanes. Thus, non-bus travel time will be affected negatively in this case. To improve the situation, a traffic system with priority bus lanes is introduced. The questions are how good the traffic performance in each bus lane type is and what would be the threshold in deciding bus lane type for the specific situation. The research aims at answering the said questions.

This paper consists of 7 main parts. The overview is presented in this section, Section 1 – Introduction, and then followed by Section 2 – Literature Review, in which the theoretical background of the research is discussed. The research objectives are presented and elaborated in Section 3. Section 4 describes in detail the methodology used in this paper. Section 5 concerns simulation tests with assumed input data. A case study is scrutinized in Section 6 to evaluate the real improvement when the model is applied to the actual case. And finally, the paper ends with several conclusions and recommendations presented in Section 7.

2. LITERATURE REVIEW

There have been a number of research papers focusing on bus priority schemes. These bus priority schemes such as reserved bus lanes, bus-only streets, with-flow interior bus lanes, exclusive median bus ways have been implemented in many urban areas all over the world. With the assignment of special lanes to buses, the level of service of the vehicular traffic was
not affected adversely and this assignment created a reduction in the travel time and an increase in the speed of buses (Cox, 1975). However, during off-peak periods or when the traffic is low, the bus lane has little impact on buses (Shalaby and Soberman, 1994). If an exclusive bus lane is provided under highly heterogeneous traffic conditions, the maximum permissible volume to capacity ratio that will ensure a level of service of C for the traffic stream comprising all the motor vehicles, except the buses, is about 0.53 (Venkatachalam and Perumal, 2008). In other words the impacts of exclusive bus lanes are significant and with utilization of the exclusive bus lanes, the operational efficiencies of buses and the general traffic are improved so much (Lin, 2010). The impacts of reserved bus lanes on both bus and automobile performance were also measured by comparing relative speed changes of buses and automobiles and the average circulation rate of bus trips for a real case in Seoul, Korea (Kim, 2003). The reserved bus lane can improve bus travels but it may affect the performance of adjacent lanes. Using macroscopic simulator TRANSYT-7F, Shalaby (1999) concluded several impacts of reserved bus lanes for the study case in downtown Toronto, Canada. The research showed that the performance of the average bus improved and the performance of adjacent through traffic deteriorated.

Some characteristics of bus lanes were also compared with each other. Dahlgren et al. (1997) defined circumstances in which high occupancy lanes are less effective than general purpose lanes in reducing delay. To get this, the authors built a model that combined queuing theory and mode choice theory to compare four alternatives: add a high occupancy vehicle lane, add a general purpose lane, convert an existing lane to a high occupancy lane and do nothing. They concluded that when applying the model in a wide range of typical situation, adding a general purpose lane would be even more effective than adding a high occupancy lane. In addition, Huanyu et al. (2003) considered bus-only and high occupancy vehicle lanes two common occupancy-based preferential facilities on highway and used the CORSIM simulation model to develop a decision model for determining whether a freeway preferential bus lane can be justified under prevailed conditions. Furthermore, the advantages of exclusive bus lane were surveyed when Seo et al. (2005) set up a methodology and criterion of exclusive bus lane based on finding a travel equilibrium point. This point was identified by making the travel time of buses and automobiles equal after operation. Since then, they recognized that the exclusive bus lane is useful only at equilibrium points with specific total traffic volume and bus volume.

Recently, several studies have focused on bus priority lane with different approaches. Sakamoto et al. (2007) analyzed real data to identify the effectiveness of bus-priority lanes as a countermeasure for traffic congestion in Shizuoka, Japan. However, because the approach compared two periods, before and after the implementation of BRT, it lacked a comprehensive investigation into concerned factors as well as a comparative analysis on the effects of each bus lane type. Meanwhile, Minh et al. (2007) also modeled bus lane priorities in a motorcycle environment using SATURN with the data collected in Hanoi, Vietnam. However, with this mesoscopic simulation, the individual vehicle behavior was not modeled. Therefore, it affected the accuracy of the final results.

It is clear from the review of literature that the choice of bus lane types and their effects on vehicle travel times have received less attention. How the vehicle travel times change in each case of bus lane type has not been analyzed and compared appropriately. Therefore, it is necessary to conduct a research on these issues.
3. RESEARCH OBJECTIVES

The main objectives of this paper are:

- to evaluate the effectiveness of the three types of bus lane treatment, including exclusive bus lane, ordinary lane and especially bus priority lane in the improvement of traffic conditions; and,

- to assess the importance and the sensitivity of main road traffic volume, the average number of passengers on bus in choosing bus lane treatment.

4. METHODOLOGY

4.1 Ideas for Bus Priority Lane Deployment

The lane changing model in PARAMICS is implemented using two devices, namely gap-acceptance policy and historical record of suitability gap availability (Quadstone, 2004). Considering a two-lane per direction segment, the gaps are illustrated as in Figure 2.

\[
\begin{align*}
\text{Lead gap} & \quad \text{Lag gap} \\
(g_1) & \quad (g_2)
\end{align*}
\]

Figure 2. Lead gaps and lag gaps

\[
\begin{align*}
g_1 & > d_{\Delta V_1} + hv_1, \text{ and } \quad g_2 > d_{\Delta V_2} + hv_2 \\
d_{\Delta V_1} & = t_{ro} + \frac{\Delta V_1}{D_1}, \quad d_{\Delta V_2} = t_{ro} + \frac{\Delta V_2}{D_2} \\
\Delta V_1 & = v_1 - v_0, \quad \Delta V_2 = v_0 - v_2
\end{align*}
\]

where,

\[
\begin{align*}
v_N: \text{ the current speed of Dynamic Vehicle Unit } N (DVU_N), \text{ and } \\
D_N: \text{ the maximum deceleration of } DVU_N.
\end{align*}
\]

The lane changing behavior depends not only on the above gaps, but also awareness factors (\(\alpha_{\text{awareness}}\)) to change lanes. Occasionally, drivers meet acceptable lead gaps, lag gaps, but they do not want to take a lane changing action. The probability for a vehicle changing lanes is:

\[
P_i^{\text{changing lane}} (t) = \alpha_{\text{awareness}} \cdot P(\text{Lead gap accept tan ce}) \cdot P(\text{Lag gap accept tan ce}) \\
= \alpha_{\text{awareness}} \cdot P(G_i^{\text{Lead}} (t) > G_i^{\text{critic-Lead}} (t)) \cdot P(G_i^{\text{Lag}} (t) > G_i^{\text{critic-Lag}} (t))
\]

With the above road segment, if \(\alpha_{\text{awareness}}\) and \(\beta_{\text{awareness}}\) are awareness factors to change from lane 1 to lane 2 and lane 2 to lane 1, respectively, the probability of increasing one vehicle (by lane change) on lane 1 would be:
\[ P_{\text{Increase\_lane\_1}} = 1 + (\beta_{\text{awareness\_priority}} - \alpha_{\text{awareness\_priority}}) x G_{i,\text{Lead\_priority}} (t) > G_{i,\text{Lead\_priority}}^{\text{crit}} (t) x P_{\text{Girth\_priority}} (t) > G_{i,\text{Girth\_priority}}^{\text{crit}} (t)) \] (5)

Comparing the two mentioned types, namely the priority and the ordinary, the awareness factors are quite different because of the recognition of priority lanes for buses. It is easy to see that the awareness factor for changing lane from lane 1 to lane 2 in the priority case is larger than that in the case of the ordinary lane. Meanwhile, its awareness factor for changing lane from lane 2 to lane 1 is smaller than that in the ordinary case. If assuming that the traffic situations such as lead gaps, lag gaps and the number of vehicles in the road segment are the same in the two above cases, it can be seen that:

\[ 1 + (\alpha_{\text{awareness\_priority}} - \beta_{\text{awareness\_priority}}) x x_{i,\text{Lead\_priority}} x x_{i,\text{Girth\_priority}} > 1 + (\alpha_{\text{awareness\_ordinary}} - \beta_{\text{awareness\_ordinary}}) x x_{i,\text{Lead\_ordinary}} x x_{i,\text{Girth\_ordinary}} \] (6)

or \( P_{\text{Increase\_Lane\_1\_1}} < P_{\text{Increase\_Lane\_1\_1\_1}} \) or \( \text{Traffic\_density\_on\_Lane\_1\_Priority} < \text{Traffic\_density\_on\_Lane\_1\_Ordinary} \) (7)

On a road segment that is long enough for a bus not to change lanes, the bus travel time on that road segment is directly proportional to the traffic density on that bus lane. Therefore, bus travel time on lane 1 in the priority lane case is usually smaller than that in the case of the ordinary lane. The advantages in bus travel time when deploying bus priority lanes instead of ordinary lanes can be seen clearly. But how much the reduction would be and how it impacts on the non-bus movement, will be the subject of this study.

4.2 Algorithm in PARAMICS Programmer Module

Using C++ and PARAMICS Programmer module to override the default lane changing model in Paramics, the research created a bus-priority plugin (a dynamic link library (DLL)) to simulate the case of priority lane. The algorithm for this plugin is shown in Figure 4. In this plugin, functions for checking and changing lanes are called for each simulation time step. The distances between the buses and those vehicles are determined by the following formula:

\[ d_{\text{bus}(i)\_j} = \sqrt{(x_{\text{bus}(i)} - x_{(j)})^2 + (y_{\text{bus}(i)} - y_{(j)})^2} \] (8)

where \( (x_{\text{bus}(i)}; y_{\text{bus}(i)}) \): coordinates of bus \( i \)

\( (x_{(j)}; y_{(j)}) \): coordinates of vehicle \( j \) moving in front of bus \( i \) on lane 1.

The paper assumes that, through rear-view mirrors, the visibility of the driver of leading vehicles to recognize any bus at the rear is in the range \( D \) from 20m. to 60m. Therefore, vehicles within the distance of 20m. – 60m. ahead from the bus will have following responses:

- If a vehicle (non-bus) and the bus travel on the bus priority lane (the vehicle now travels on lane 1), the vehicle, if possible, changes its lane to lane 2, to give way for the coming bus (as shown in Figure 3).
- If the vehicle now travels on lane 2, this vehicle will not be allowed to change lanes to lane 1 (bus priority lane).
Figure 3. Vehicle changes lane to give way for the bus

The above lane changes have two exceptions: the vehicle wants to turn left at intersections and the vehicle cannot change lanes due to unavailability of acceptable gaps to change lanes.

Figure 4. Algorithm used in PARAMICS for bus priority lane plugin

5. SIMULATION TESTS

5.1 Traffic Network and Assumed Data

The paper builds a hypothetical traffic network with left-hand drive orientation. In this network, zone 1 and zone 2 are the main zones, and other zones are on the side streets. The lay-out is illustrated in Figure 5.

The main street has 2 lanes for each direction. Each direction of the side streets has one lane. At each intersection, the network has slip lanes for vehicles that want to turn right. The length of the slip lanes ranges from 90 to 100 m. on the main street are around 90-100m and 30 to 40 m. for the side streets. Traffic signals at intersections include 3 phases and the split between
the main street and side streets is 75:25. Two bus stops are designed on the main street with a dwell time of 30 sec. Proportions are proposed for cars, small trucks, big trucks to be 77%, 13% and 10% respectively.

![Figure 5. Traffic network](image)

In PARAMICS, the process of releasing the vehicle is controlled by travel demand. There are two kinds of travel demand mentioned in this paper, one for the main street and the other for the side streets. These travel demand types are specified in the form of origin-destination matrices. The percentages of releasing vehicles in each period are specified in the profile file of the PARAMICS core program. This study assumes that the side street demands are invariable while the main street demand is variable. The side street traffic volumes are always 300 vph in this research. The main street demand is divided into 7 levels corresponding to seven demand patterns. In each pattern, the simulation time is 5 hours from 6 AM to 11 AM. Each demand pattern has a warm-up period (from 6 AM to 7 AM) with the traffic volume of 500 vph, a transition period and a peak hour period with its traffic volume. The warm-up period makes the simulation model more realistic and the peak hour periods are used to calculate vehicle travel times, which is considered at 7 traffic levels: 500 vph, 750 vph, 1,000 vph, 1,250 vph, 1,500 vph, 2,000 vph, and 2,500 vph.

### 5.2 Results from the Simulation Tests

The relationships between the main traffic volume (traffic volume of the main street) and vehicle travel times are non-linear curves. Generally, the vehicle travel time increases when the main street traffic volume increases.

![Figure 6. Relationship between travel times and main street traffic volume](image)

The effects of the other vehicles on bus operations create changes in the bus travel time among the cases. In Figure 6, it is clear that the bus travel time is lowest in the exclusive case and highest in the ordinary lane case. The bus priority lane case can improve the bus travel time significantly compared with the ordinary lane case. For non-bus travel time, it is
straightforward to see that the travel time is lowest in the ordinary lane case and highest in the exclusive bus lane case. That is reasonable because the road surface area for non-bus use is the largest in the ordinary lane case and the smallest in the exclusive lane case.

6. A CASE STUDY

The study site is a main urban street which lies partly on the Route No. 351 and partly on Route No. 36 leading to Nagaoka Station (Figure 9). From field inspection, this urban street segment has high bus traffic and also a high traffic volume in comparison with other areas in the city. As a gateway to Nagaoka Station, this arterial plays an important role in the traffic network of the city. In the collection of traffic data of this urban street, 10 cameras were placed as shown in Figure 7 to observe the traffic during the period from 7:30 AM to 9:30 AM. Four cameras were set at 4 intersections to record the traffic flow through the main street, the side streets and turning traffic movements. The remaining cameras were used to obtain video footage at bus stops along this route. To get the accuracy of travel time calculation and the time of bus arrival, all cameras started at the same time. In addition, the camera’s clocks have been synchronized. The arrangement is as follows:

After capturing the traffic situation, the captured video was analyzed in the Transportation Laboratory to obtain the traffic proportion (Figure 8), traffic volumes, turning proportion, bus interval, bus dwell time, car travel time, bus travel time, traffic signals at intersections and offset. Based on the data observed, the main street traffic volume on the direction towards the station is around 514 vph, and 365 vph on the opposite direction during the peak hour. The detailed traffic volumes are displayed in the part of comparison between simulated flows and observed flows at the end of the following calibration process. All the traffic information, control information and geometric information of the study site are inputs to the PARAMICS Modeler – a microscopic simulation software. The displays from the map and the interface of PARAMICS are as shown below.

6.1 Model Validation

Observed traffic flows at 32 points in the traffic network during the peak hour were divided into 4 intervals, from 8:00 to 8:15, 8:15 to 8:30, 8:30 to 8:45 and 8:45 to 9:00. Meanwhile, the simulated traffic flows were obtained from PARAMICS by setting a period of 15 minutes to collect data at 32 points during the peak hour. From the simulated results and observation data,
the traffic flows in the 4 intervals during the peak hour from 8:00 to 9:00 are plotted around the 45-degree line, as shown in Figure 10. The values of simulated traffic flows and observed traffic flows cluster closely to the 45-degree line. The relative errors of traffic flows at all observed points are less than 15 percent.

![Figure 9. The study area (left) and simulation nodes, links, zones built in PARAMICS (right)](image)

Figure 9. The study area (left) and simulation nodes, links, zones built in PARAMICS (right)

![Figure 10. Comparison between simulate traffic flows and observed traffic flows](image)

Figure 10. Comparison between simulate traffic flows and observed traffic flows

The travel times are measured on the road segment A1A2 (as in Figure 7) for vehicles traveling from intersection 1 to intersection 4 from recorded video tapes and from the PARAMICS modeler. Vehicles were classified into 2 groups, bus and non-bus. The comparisons for every interval during the peak hour are shown in Figure 11.
Figure 11. Vehicle travel time validation

The travel times of bus and other vehicles for each direction on the main street in the observation case and simulation case are approximately the same. The relative errors of travel times of bus and non-bus are less than 5% at each considered interval.

6.2 Comparative Analysis

After validating the model for the ordinary lane case, the research investigates 2 more cases, the exclusive lane case and the bus priority lane case, based on the available traffic network. These 2 cases utilize the geometric figures, current traffic volumes, bus schedules, etc. but the policy for traffic has been changed. With the same traffic conditions but with differences in policy (ordinary lane case, bus priority lane case and exclusive lane case), the traffic performances during peak hour from 8:00 to 9:00 in 3 cases are compared. Specifically, the bus travel time and non-bus travel time on the direction towards the station for each interval and for each bus lane case are compared. The peak hour was divided into 4 intervals, from 8:00 to 8:15, from 8:15 to 8:30, from 8:30 to 8:45 and from 8:45 to 9:00. To show more clearly the advantages and disadvantages of each treatment, the reduction or increase in travel time among cases will be illustrated in this figure.

On the studied direction, the bus travel time and non-bus travel time at each interval during the peak hour are displayed in Figure 12.

From the above figure, the bus travel times in the case of exclusive bus lane and bus priority lane are reduced significantly compared with bus travel time in the ordinary lane case. Meanwhile, non-bus travel time does not change so much when comparing the bus priority lane case and the ordinary lane case. The reductions in bus travel time in the bus priority lane case are 2.9%, 5.1%, 3.9% and 2.6% at each interval of the peak hour in comparison with the ordinary lane case. For the exclusive bus lane, reductions in bus travel time were 5.6%, 6.3%, 8.0% and 4.0%. On the average, the bus travel times in the bus priority lane case and exclusive bus lane case have been reduced by 3.63% and 5.98%, respectively during the peak hour. As for non-bus travel time, the increases were 1.0% (period from 8:00 to 8:15), 1.6% (period from 8:15 to 8:30), 2.3% (period from 8:30 to 8:45) and 2.2% (period from 8:45 to 9:00) for the bus priority lane case compared with the ordinary lane case. Meanwhile, non-bus travel times in the exclusive bus lane case increased significantly by 2.8%, 5.5%, 12.2% and 7.3% at each 15-minute interval of the peak hour period. Generally speaking, the non-bus travel times were not significantly different between the ordinary lane case and the case of bus priority lane. The non-bus travel times on the average increased by about 1.78% for the bus priority lane case and 6.95% for the exclusive bus lane case during the peak hour. Although the exclusive bus lane can reduce the bus travel time significantly, the non-bus travel time
also increases greatly. With the bus priority lane treatment, bus travel time can be reduced considerably while there is a slight increase in non-bus travel time.

Figure 12. Vehicle travel time comparison for each bus lane case per 15-minute interval

6.3 The Decision on Choosing Bus Lane Type
During the peak hour, there were 28 buses that passed segment A1A2 on the direction being studied. Based on the observation, the average number of passengers on each bus was 19.4 with the standard deviation of 3.2 for 28 buses and on each non-bus is 1.25 with the standard deviation of 0.4 for 110 passenger cars. Converting all bus travel times and non-bus travel times into passenger travel time, the time needed for one passenger going from intersection 1 to intersection 4 can be estimated with the results illustrated in Figure 13.

Figure 13. Comparison of passenger travel times
It is clear that compared with the exclusive bus lane and the ordinary lane case, the bus priority lane case had better performance in reducing passenger travel time. For this direction, the bus priority lane treatment can reduce travel time by 1.2 sec. (or 0.8%) per passenger in comparison with the current ordinary lane case. Meanwhile, the exclusive bus lane treatment made the passenger travel time increase by 1.3 sec. (equivalent to 0.8%). Although the exclusive bus lane can improve bus travel time significantly, its negative impacts on non-bus operation are significant in this case. Therefore, bus priority lane is the better policy which can improve bus operation and reduce negative impacts on non-bus simultaneously.

6.4 Sensitivity Analysis
The traffic volume and the number of passengers change every day, every hour. In addition, it is so difficult to exactly count the number of passengers on all buses and all passenger cars. Thus, the decision on choosing bus lane type would be changed according to the traffic situation. The research preserves the bus schedule in this study site and conducts an analysis of choosing bus lane treatment based on ranges of the number of passengers and main street traffic volume. The differences in passenger travel time between cases are formulated as follows:

\[ \Delta_{Pr}(X_1, X_2) = T_{Passenger}^{Ordinary} - T_{Passenger}^{Priority} \]  (9)

\[ \Delta_{Exc}(X_1, X_2) = T_{Passenger}^{Ordinary} - T_{Passenger}^{Exclusive} \]  (10)

where,

- \( \Delta_{Pr}(X_1, X_2) \): difference in passenger travel time between the ordinary case and the priority lane case (sec/passenger)
- \( T_{Passenger}^{Priority} \): passenger travel time on A1A2 segment on the direction to the station in the priority lane case (sec/passenger)
- \( T_{Passenger}^{Ordinary} \): passenger travel time on A1A2 segment on the direction to the station in the priority lane case (sec/passenger)
- \( X_1 \): traffic volume on the main street (vph)
- \( X_2 \): average number of passengers on buses (passengers)

As being seen in equations (9), (10), the bus priority lane or the exclusive bus lane case is considered a better case compared with the current ordinary lane case when the value of \( \Delta_{Pr}(X_1, X_2) \), or \( \Delta_{Exc}(X_1, X_2) \) is positive. The bigger the values of \( \Delta_{Pr}(X_1, X_2) \), \( \Delta_{Exc}(X_1, X_2) \), the better the cases of bus priority, exclusive lane respectively in comparison with the ordinary lane case. The research investigated the three cases of bus lane with varying levels of main street traffic volume. The considered values of main road traffic volume are 300 vph, 400 vph, 500 vph, 800 vph, 1,000 vph, 1,300 vph, 1,500 vph and 1,900 vph. At each value of main street traffic volume, the output travel times were obtained from PARAMICS after 10 times of running for each case of bus lane. The relationships are illustrated as in Figure 14.
From Figure 14, the violet lines and blue lines are contours of which values represent the differences in passenger travel time between the case of ordinary and bus priority lanes. Similarly, the yellow lines are also contours of which values represent the differences in passenger travel time between the ordinary case and the exclusive bus lane case. There are two main points that the research would like to bring out in this figure. The first one is the area distribution. It is easy to see that, the area with high number of passengers on bus and low main street traffic volume is the most suitable for exclusive bus lane treatment (the area with yellow lines). Meanwhile the area with the low number of passengers in the bus and high main street traffic volume is good for ordinary lane case (the area with violet lines). The middle area with blue hatch, between the area for exclusive bus lane and the area for the bus priority lane is proper for deploying bus priority lanes. If the bus priority lane were deployed in this area, the passenger travel time can be reduced by up to 1.8 sec. when traveling on the 500-meter main street segment. The second point the research wants to mention is the slope of the lines. Both the main street traffic volume and passenger numbers are very important factors in choosing bus lane types. However, the slopes in the case of the exclusive bus lane are steeper compared with those in the other cases. It means that the dependence on passenger numbers in the exclusive bus lane case is very high, higher than that on the main street traffic volume. These slopes decrease gradually from the case of exclusive bus lane to priority bus lane and finally to the ordinary lane case when the main street traffic volume increases. At that moment, the dependence on the main street traffic volume becomes more important than that on the passenger numbers.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions
The research comparatively analyzed the impacts of the three popular types of bus lane in Japan by using PARAMICS as a tool to simulate the bus lane types. The results showed that although the exclusive bus lane type can improve bus service significantly, its negative
impacts on other types of vehicles are also significant. If deployed at the study site, the exclusive bus lane would make the passenger travel time increase by 1.3 sec. on a 500-meter long urban street. Meanwhile, because of the flexibility in choosing lane in the priority bus lane case, developing bus priority lane at this study site can reduce 1.2 sec. for each passenger traveling the main street.

In addition, the research conducted a sensitivity analysis in choosing bus lane types when the main street traffic volume and the number of passengers in the bus vary. The analysis has shown that the exclusive bus lane is proper for conditions when the main street traffic volume is low and the number of passengers in buses is high. The passenger travel time improvement depends heavily on the passenger numbers. When the main street traffic volume increases, it has been found out that there is an area defined by a range of main street traffic volume and passenger number that are suitable for the priority bus lane case and an area defined by a range of main street traffic volume and passenger number that are suitable for the ordinary lane case. The dependence on the number of passengers in improving passenger travel time gradually switches to that on the main street traffic volume.

7.2 Recommendations
The research would like to analyze the advantages of bus priority lane in the aspect of city planning for bus operations. Calibrations of parameters as well as further analyses of the model are beyond the scope of this research. That should be dealt with by further studies. In addition, the final results for exclusive bus lane in this research are applied only for short periods. For long periods, because of being congested caused by bus lane operation, private vehicle users choose other routes or give up driving and take a bus to save travel time with respect to TDM policies. The area distribution in choosing bus lane type should be changed. Therefore, the bus lane policies would be appropriate for the long-distance travelers so that the private vehicle users shift their modes or change their routes.

- To provide city planners with sufficient information for making decisions of what bus lane policy to implement, a lengthy segment with a comprehensive investigation on factors such as bus schedule, tuning flow rate, effective distance between intersections and the awareness of drivers should be considered. In addition, not only in terms of travel time but also other aspects as specific geometrical conditions, convenience and safety are also necessary terms needed to be concerned and completed in future studies.
- Improving bus service and minimizing the negative impacts on other vehicles simultaneously are the essential targets of traffic policies. These targets can be obtained from the deployment of not only bus priority lanes, exclusive bus lanes but also bus signal priority system. Thus, focusing on studies about bus signal priority as well as combining the operations of bus priority lane and bus signal priority system is also a promising aspect for future works.

REFERENCES


